Nanoscale Ordering Discovered in Gallium Nitride

Mg Dopant Found to Cause "Microsuperlattice" Formation

A Berkeley lab team, using the facilities of the National Center for Electron Microscopy (NCEM), has discovered that the addition of Mg to GaN can cause a unique form of ordering in the growing crystal. The discovery has important implications for the use of III-V nitrides in green, blue, and ultraviolet-emitting diodes and lasers.

Recent research in the III-V nitride materials systems (i.e. GaN and its alloys with AlN and InN) has led to the development of semiconducting materials that can generate light both in the previously inaccessible blue and ultraviolet regions of the spectrum and also, with greater efficiency than accessible before, in the green region. Highly efficient blue light emitting diodes and lasers based on these materials are now in production. The applications for these devices range from high-density data storage to, when they are combined with high efficiency phosphors, the potential eventual replacement of inefficient incandescent light sources.

An essential component of all of these light emitting devices is a "p-n junction." Achieving the correct "doping" of the semiconducting materials in the junction, which creates the required deficit of electrons (excess of "holes") on the p-side of the junction has been a continuing challenge and would be an important factor in improving device performance. Mg is the p-type dopant used currently, but its performance is far from ideal. It has long been suspected, but until now never proved, that this is due to a non-uniform distribution of Mg that develops during crystal growth.

The Berkeley Lab team discovered a previously unanticipated consequence of Mg-doping in GaN by studying its behavior in single crystals and thin films using high resolution transmission electron microscopy. First, in Mg-doped single crystals that were grown under high temperature and pressure conditions, the workers discovered that a "microsuperlattice" of planar defects with a regular spacing of 10 nm is formed (see figure). Due to the intrinsic symmetry of the crystal, the growth surfaces of GaN have either "N-polarity" or "Ga-polarity;" the workers found that this spontaneous ordering occurred only for growth on the N-polarity surface. Further high-resolution analysis at NCEM resolved the structure of the defects and showed that they are rich in Mg. The team also examined films heavily doped with Mg and grown by the standard metall-organic chemical vapor deposition (MOCVD) used to grow commercial devices. Similar, ordered structures were also observed in these films.

The mechanism for this ordering phenomenon is not yet completely understood, but it appears to be qualitatively similar to the "polytypoid" formation that occurs in the growth of oxygen-rich AlN. The LBNL work does clearly explain, however, why it is difficult to obtain high levels of p-type doping with Mg in GaN; at high Mg concentrations, the Mg diffuses to these planar defects where it is electrically inactive as a dopant. Future TEM studies at NCEM are aimed at identification of specific growth conditions that will eliminate or control this Mg segregation so that stable p-doping can be achieved.

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